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Economic Feasibility And Social Consideration For Jamaica Expanding Its Renewable Portfolio Mix Upon A Microgrid System

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by

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DEDICATION

I dedicate this thesis work to my dearest wife Shavel Fagan who was instrumental in me pursuing this degree. To my parents Dudley and Adelle Fagan and my siblings, Kenrick and Oral who taught me, provided for me throughout my educational pursuits and always pushed me to achieve the highest academically.

Finally, to my dearest darling gift from our heavenly Father above, my daughter Calleigh Johannah Fagan. I hope this paper will be an example for you to show you that anything is possible if you endeavor for the greatest that life has to offer.

ACKNOWLEDGEMENTS

I would like to acknowledge first and foremost the Creator and the Almighty Heavenly Father God for giving me the opportunity, strength, knowledge, and ability to undertake this study and complete it satisfactorily. Without his blessings, this achievement would not have been possible.

Secondly, I would like to acknowledge my advisors, Professors Stephen McNeill and Herbert Ginn of the Mechanical and Electrical Department respectively at the University of South Carolina. Professor McNeill, afforded me his time, knowledge and research experience and guided me through this thesis paper. Professor Ginn was the only person from the Electrical Department that bequeathed me his time and expertise by joining my thesis board and afforded me valuable insights and guidance. They both steered me in the right direction and without them, I would not have been able to initiate and complete this paper.

Finally, I would also like to thank the subject matter experts O'Neil Morgan of ICF, a global consultant firm, and Professor Andrew Sabalowsky of the Mechanical Department at University of South Carolina. They were called upon in the 11th hour and provided passionate and invaluable recommendations, along with timely literature and resources which enhanced my overall research paper. This accomplishment would not have been possible without each individual of which I am truly grateful.

ABSTRACT

According to Lund (2007), energy sources can be divided into three main categories: fossil fuels, nuclear resources, and renewable energy sources. Renewable energy technologies are on the upward trend both residentially and commercially, with many studies being conducted to optimize its use. There are many opportunities that exists for Jamaica to utilize renewable sources as energy for generating electricity.

Several sources, including the Ministry of Science, Technology, Energy, and Mining of Jamaica, states that the country sources just over 90 percent (90%) of its electricity capacity from petroleum-based power plants. Along with a high petroleum fuel source power-generation, the method used to distribute power across the country is the high-voltage transmission system which is the traditional method of electrification. The current oil reserves around the world are finite and as they are depleted, prices for petroleum will inadvertently affect the prices for everything else from products to services.

This study seeks to identify whether the implementation of a higher mix of renewable-source-powered microgrid system would be economically sustainable, in comparison to Jamaica's natural gas and petroleum based fuel mix. It is hoped that this evaluation on implementing renewable energy as power source utilizing a microgrid system, will contribute to existing body of knowledge.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CARICOM..Caribbean Community

CSERS ....Caribbean Sustainable Energy Roadmap and Strategy

DER ....Distributed Energy Resources

GDP ....Gross Domestic Product

GHI.. Global Horizontal Irradiance

JPS..Jamaica Public Service Limited

MSW... Municipal Solid Waste

PV .... Photovoltaic

RE .... Renewable Energy

RMGs ....Reconfigurable Microgrids

SMEs ....Subject Matter Experts

CHAPTER I
INTRODUCTION

Background

As stated by Anjorin (2014), economic development and a nation's maintainability is supported by energy sufficiency. He also highlighted that access to sustainable sources of energy is directly proportional to economic growth. According to Auth, Killeen, Konold, Musolino, and Ochs (C-SERMS) (2015), every CARICOM member state exhibits significant and largely unexploited potential for developing renewable energy resources. If fully developed, these resources could transform many states into net energy exporters.

The country of Jamaica, as of 2016, sources just over 90 percent (90%) of its electricity use from petroleum-based power plants based on data received from CIA: World Fact Book. Because Jamaica lacks domestic petroleum resources, it depends entirely on imports, resulting in significant economic and environmental costs for the country. Along with a high petroleum fuel source power-generation, the method used to distribute power across the country is the high-voltage transmission system which is the traditional method of electrification. Figure 1.1 and Figure 1.2 shows the current setup of Jamaica's traditional power transmission system and a simple diagram of the flow of power in the traditional system respectively.

According to Ahmed, Konold, Lucky, Makhijani, Ochs, and Weber (2013), the current grid has high transmission and distribution losses, at 22.3% in 2011; this is down from a high of 24.7% in 2008 but is still significantly higher than the national target of 17.5%. Yet even Jamaica's target share is high by international standards: in the United States, total transmission and distribution losses average only about 7% annually (Ahmed, et al., 2013).

With all the factors mentioned earlier in play, the current electrification and economic situation for the country of Jamaica is not sustainable. As illustrated in Figure 1.3 and 1.4, Jamaica is a long way from meeting its electricity needs and experiences more losses than efficiency according to Figure 1.5. The Jamaican government however has taken steps to reduce the demand on the main power supplier, Jamaica Public Service Company (JPS), by implementing an energy policy which makes it easier for private companies to start power plants. The Jamaica Energy Policy report also outlined a realistic strategy for improving the energy matrix to the year 2030, see Figure 1.6.

When the territories of the Caribbean are mentioned in a discussion, the first thoughts are not often of how much oil reserves they have, but often times of how thriving their beaches are. This is due to the fact that there are currently not many Caribbean countries drilling for oil whether inland or offshore.

Problem Statement

According to Zaremba (2017), only three Caribbean countries have oil reserves Cuba, Barbados, and Trinidad and Tobago, the latter of which is the only major exporter of oil from the Caribbean. Oil, often times referred to as petroleum, is processed into fuel for combustion or heat. The current oil reserves around the world are finite, and as they are depleted, prices for petroleum will inadvertently affect the prices for everything else from products to services. Electricity prices for Jamaican residents are among the highest in the world, at around 40 U.S. cents per kilowatt-hour, having more than doubled between 2005 and 2011 as a result of rising global oil prices and electricity grid losses (Ahmed et al., 2013). Ahmed et al., 2013, based on their studies, highlighted that the high price of electricity is a major barrier to Jamaica's economic development and a leading cause of business failure in the country (p. 11).

Energy efficiency improvements can result in significant cost savings for the country, especially for large and energy-intense sectors. Jamaica has one of the highest rates of both duration and frequency of electricity service interruptions in the Latin America and Caribbean region, with 27 interruptions totaling 50 hours of outages in 2008 (Ahmed et al., 2013, p. 63). If Jamaica is to continue on its current electrification path, with its fuel source and distributing process, the country would remain stagnant and eventually decline financially as world prices are affected by oil shortage.

Purpose of Study

This study seeks to identify whether the implementation of a higher mix of renewable-source-powered microgrid system would be superior in both sustainability and power output, in comparison to Jamaica's natural gas and petroleum based fuel mix. An official report from C-SERMS (2015) showed Jamaica's power capacity having only 7.8 % of installed renewable energy power source (see Table 1.1).

Significance of Study

It is hoped that this evaluation on increasing the portfolio mix of renewable power source, utilizing a microgrid system will contribute to the existing body of knowledge. This would be beneficial to the Ministry of Energy and by extension, the entire country of Jamaica on a whole, as they seek to improve energy sustainability and security.

Limitations of the Study

The two major limitations of this study is 1) the researcher's temporary inability to travel to the country of study, and 2) the time constraint to gather additional information to afford a more detailed study.

Delimitations of the Study

The researcher narrowed down the scope of this research by focusing on only two of the power generating technologies that currently exists, Advanced Natural Gas Combined Cycle (ANGCC) and Solar Photovoltaic 'Tracking'. In addition, only two energy storage systems, battery energy storage system (BESS) and air compressed storage (AE) will be analyzed.

Definition of Key Terms

Biomass: This is any organic material that comes from plants and animals, and it is a renewable source of energy. Biomass contains stored energy from the sun. Plants absorb the sun's energy in a process called photosynthesis. When biomass is burned, the chemical energy in biomass is released as heat.

Electrification: This refers to the process of generating and transmitting electrical power for consumption.

Loads: This refers to an electrical component or portion of a circuit that consumes (active) electric power.

Microgrid: This refers to a localized group of electricity sources and loads that normally operates connected to and in synchronicity with the traditional centralized electrical grid but can also disconnect to island mode.

Photovoltaics (PV): This refers to devices that generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material called semiconductors. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect.

Organization of Thesis

The thesis paper is organized by five chapters. Firstly, in Chapter One, a brief history along with the current conditions of Jamaica's electrification system is discussed; additionally, the problem statement, the purpose and significance of the study are highlighted. Other aspects covered in this chapter include the theoretical framework as well as the scope, the limitations and the definition of the key terms of the study.

Secondly, Chapter Two underscores information obtained from an extensive review of relevant literature on microgrid systems and renewable energy sources. The chapter focuses on key technologies that are current and can foreseeable be an immediate an achievable means of improving Jamaica's electricity generation system. The next chapter, Chapter Three, goes on to address the research methodology, discussing the procedures and approach used in carrying out the study.

The chief objective of this study, which was an analysis of implementing renewable energy source technology to the electrification portfolio, was recorded in Chapter Four. The chapter presented tables and figures of the results obtained in the study. The last and final chapter, Chapter Five, contains a discussion on the overall study along with the conclusion. The chapter closes the study by stating the limitations and presenting the recommendations based on the study and the results.

Table 1.1 Showing Installed Power Capacity and Share of Renewables in CARICOM Member States, as of 2015

Country	Installed Power Capacity (MW)	Installed Renewable Power Capacity (MW)	Renewable Share of Installed Power Capacity (MW)
Antigua and Barbuda	113	0.8	0.7
The Bahamas	536	0	0
Barbados	240	5.5	2.3
Belize	141.8	82.5	58.2
Dominica	27.7	7.6	28.6
Grenada	48.6	0.7	1.4
Guyana	383	55.1	14.4
Haiti	390.0*	62.4	16
Jamaica	926.4	72	7.8
Montserrat	5.5	0	0
Saint Lucia	88.6	0.2	0.2
St. Kitts and Nevis	56.4	3.2	5.7
St. Vincent and the Grenadines	52.3	6.4	12.2
Suriname	410	189	46.1
Trinidad and Tobago	2,368.00	0.01	0.005

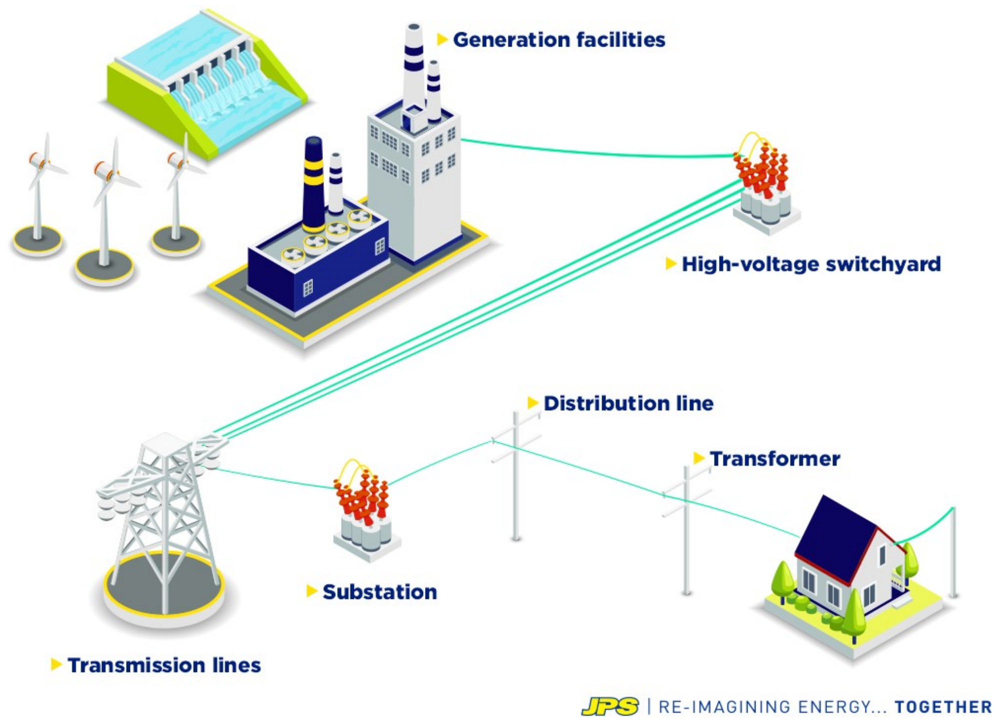

Figure 1. 1 Current Setup of Jamaica's Traditional Power Transmission System. Reprinted from https://www.jpsco.com/about-jps/how-we-serve-you/how-we-deliver-power-to-you/

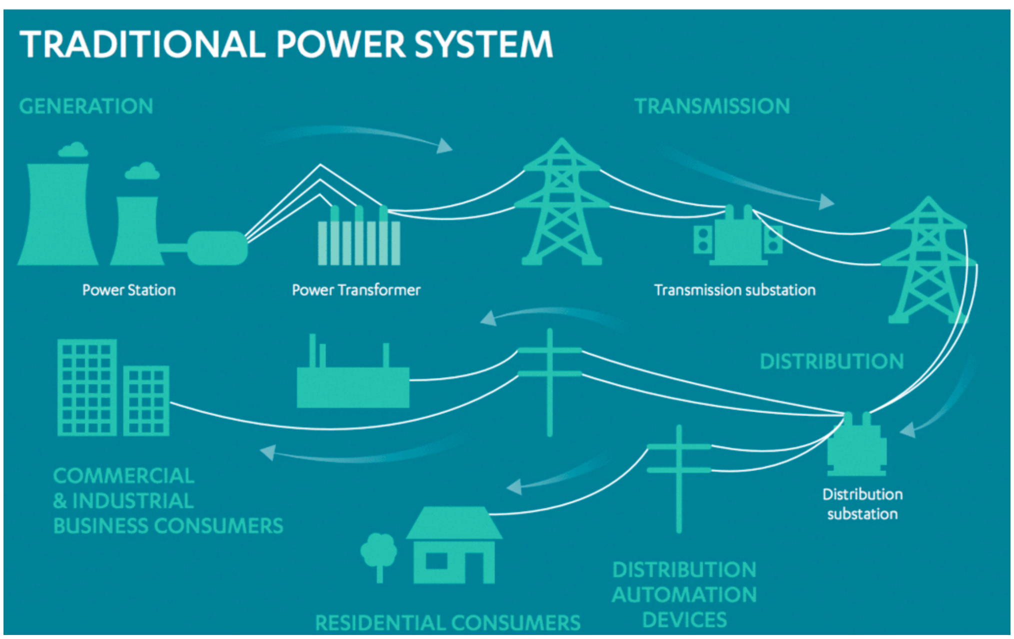

Figure 1. 2 Diagram Showing the Flow of Power in the Traditional System. Reprinted from https://www.carbonbrief.org/uk-needs-a-smart-power-revolution-says-infrastructure-commission/www-gifcreator-me_r3xltb-1

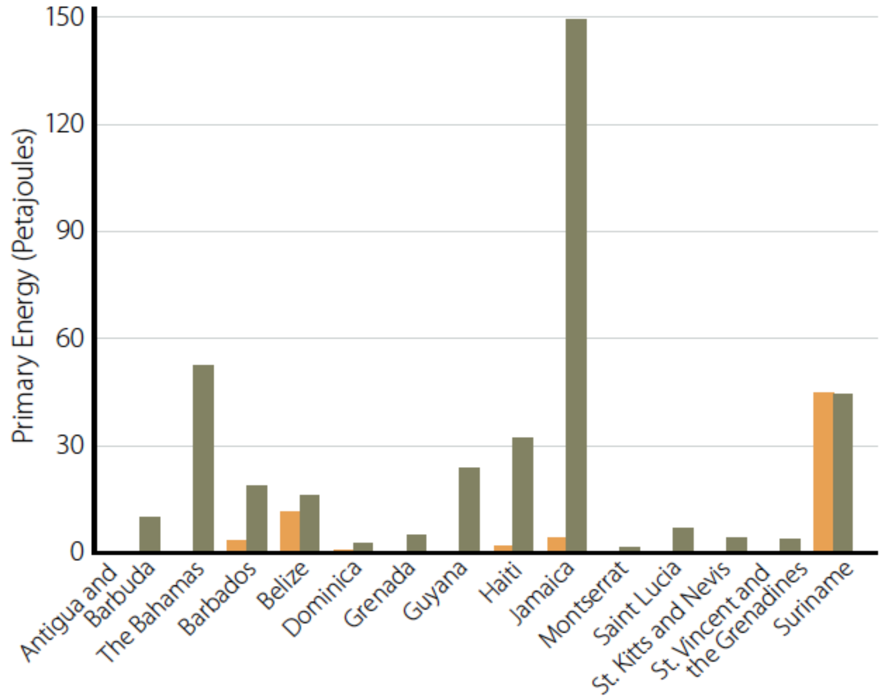

Figure 1. 3 Primary Energy Production and Consumption of Selected CARICOM Member States, 2012. Reprinted from (C-SERMS, 2015).

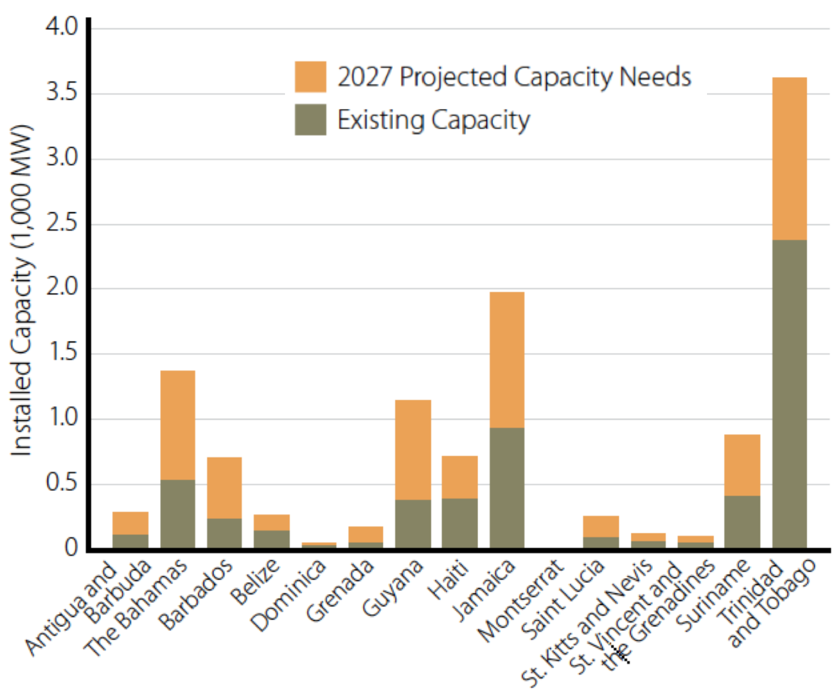

Figure 1.4 Existing Capacity and Projected Capacity Needs in 2027 (business-as usual scenario not including future energy efficiency and conservation policies and measures). Reprinted from (C-SERMS, 2015).

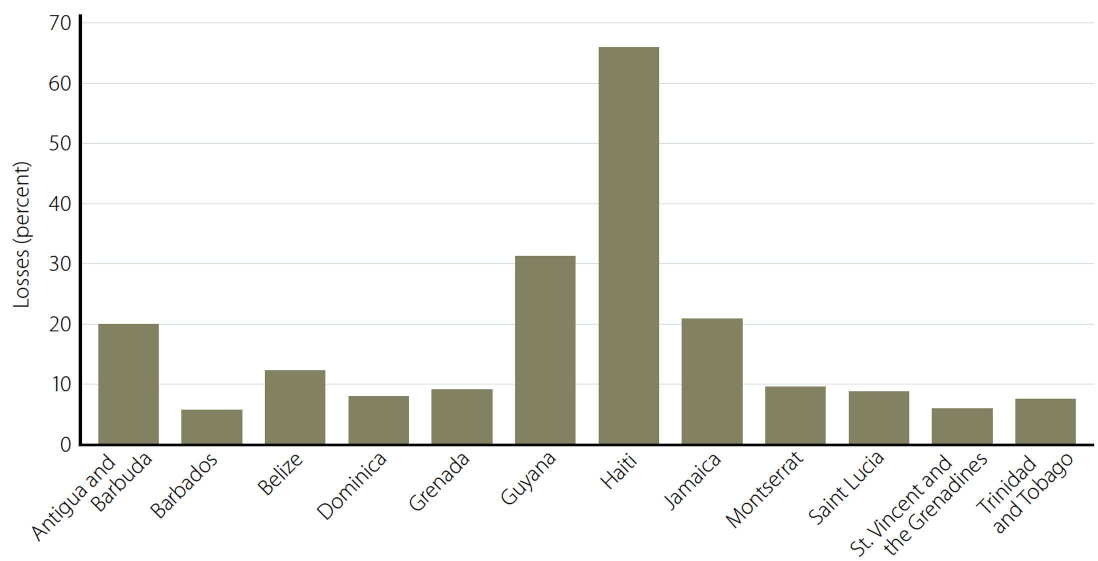

Figure 1.5 Estimated Technical and Non-Technical Electricity Losses in Selected CARICOM Member States, 2012. Reprinted from (C-SERMS, 2015).

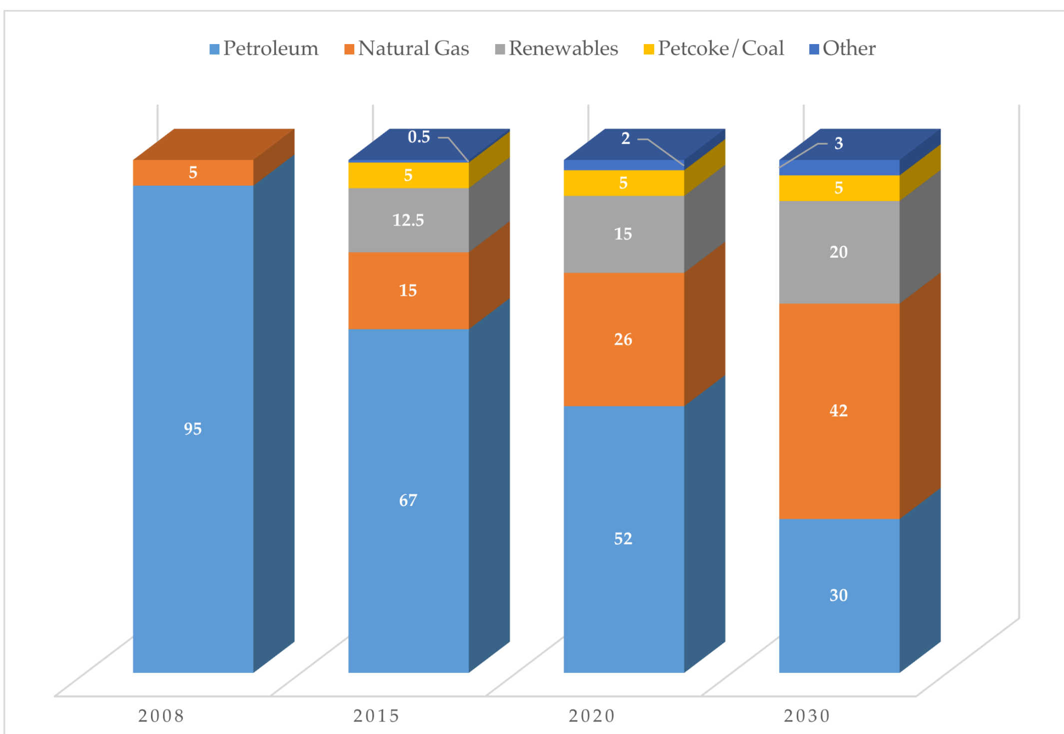

Figure 1.6 Jamaica Energy Matrix 2008 – 2030 Strategy. Reproduced from (C-SERMS, 2015)

CHAPTER II
LITERATURE REVIEW

Brief History on the Trends of Energy Sources, Storage and Safety

According to Lund (2007), energy sources can be divided into three main categories: fossil fuels, nuclear resources, and renewable energy sources. Renewable energy technologies are on the upward trend commercially with many studies being conducted to optimize its use.

Currently, in the residential (individual) area, accessibility to renewable energy technologies is growing due to enhanced affordability and efficiency, likewise does the possibilities and opportunities for its application. In contrast to traditionally centralized electricity provision systems (such as fossil-fuel-based electricity generation), renewable energy technologies allow for the decentralization of energy generation. With this comes the opportunity not only to address energy demand, but also decrease electricity costs for residents (Broese van Groenoub, McCabea, and Pojania, 2018).

Achieving Electrification-Decentralization Using Microgrid Systems

A microgrid is defined as a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that can act as a single controllable entity with respect to the grid and can operate in grid-connected or islanded modes (Khodaei, 2014). Figure 2.1 illustrates a microgrid system with various components.

Lund (2007) notably acknowledged that for a sustainable energy system, three major technological changes must be developed. These are; energy savings on the demand side, efficiency improvements in the energy production, and replacement of fossil fuels by various sources of renewable energy.

Fallahzadeh-Abarghouei, Hasanvand, Nayeripour, & Waffenschmidt (2017), established that one problem of the traditional method of distributing and generating power was related to optimal expansion of distribution system facilities to meet the load growth as well as system constraints. Fallahzadeh-Abarghouei et al. (2017) continued to state that, “In classical planning, the load growth is typically met by adding a new substation or upgrading the existing substation capacity along with their feeders.” The use of micro-grid systems to generate and distribute electricity to both residential and commercial customers is one of the most efficient and ever growing methods of electrification. When implemented, micro-grid systems can aid in reduction of electricity bills and also provide increased reliability during power consumption (Hatziargyriou et al., 2008).

Due to smart switches, Bahramirad, Kavousi-Fard, and Khodaei (2016), argued that the current generation of static microgrids is about to transition to a new generation of reconfigurable microgrids (RMG). These researchers highlighted that RMGs use remotely controlled switches to control and change the microgrid topology to ensure that desired objectives can be achieved. RMGs can provide customers with a greater degree of cost-effectiveness, efficiency, reliability, and power quality, though challenges remain.

Available Renewable Energy Sources: Current and Potential Portfolio Mix

There are many opportunities that exists for Jamaica to utilize renewable sources as energy for generating electricity. According to Ahmed et al. (2013), several past and ongoing studies have estimated renewable energy resource potential in Jamaica. The report also went on to state that, "these assessments provide an important overview of resource availability in the country, although most studies are not detailed enough or are too site-specific for the purposes of a general roadmap for the country" (pg. 37). The following are brief highlights on the different potential renewable sources.

Hydro as an Energy Source

With it being the highest percentage of energy generation in the RE source category, the hydropower has come up as the most competitive renewable technology. The major disadvantage associated with hydropower however, according to Arif, Aslam, and Hussein (2017), is the requirement of a suitable site for the location of the plant.

Wind as an Energy Source

Outside of hydropower, wind has been by far the most successful renewable electricity source worldwide, with 318 GW installed globally by the end of 2013. The costs of wind power can be as low as 4 to 7 cents per kWh in attractive locations, making it significantly cheaper than even the cheapest fossil fuel alternative. According to a 2010 report from Nexant, wind has the potential to be the fastest-growing renewable energy technology in the CARICOM region over the next two decades. A few CARICOM member states have begun developing capacity to harness the resource. Jamaica, for example, had 48 MW of installed wind power capacity in 2013 and, as of January 2015, had secured financing for an additional 36 MW (C-SERMS, 2015).

Marine Energy as Sources for Renewable Energy

Marine technology consists of tidal and wave energy as sources for renewable energy. Tidal energy utilizes the gravitational pull of the Earth and Moon while wave energy utilizes the motion present on the surface of the ocean to perform as energy source which in turns generate power. Unlike other renewable technologies mentioned in this chapter, marine energy technologies are far from commercially viable and still have prohibitively high costs (Ahmed et al., 2013, p. 59).

Many tidal power systems use a design similar to wind turbines, except the units are located underwater at the base of tidal bays and channels. Because water is roughly 1,000 times denser than air, the systems are capable of producing roughly 1,000 times more energy than wind using water moving with the same flow speed as the air.

In 2011, before the current Jamaica Electricity Act (2015) which governs the generation, distribution and sale of electricity, a wave-generated project was commenced by the Ministry of Science Technology Energy & Mining (MSTEM) and Renewable Energy and Energy Efficiency Department (REEED) to provide two coastal communities electricity. This project was eventually abandoned due to a violation of the JPS license (Ahmed et al., 2013).

Despite the current barriers, wave and tidal power may soon play an important role in some locations, such as small-island states that have extensive coastal territories. With technologies maturing and costs decreasing, wave and tidal generation could become cost-competitive in some coastal regions (C-SERMS, 2015).

Biomass as a Renewable Source

Energy can be generated from a wide variety of organic materials, including farming crop residues, forestry wastes (woody biomass), and even municipal solid waste (MSW). Both crop residue and woody biomass can be used for heat or electricity, or they can be gasified to have the same functionality as oil and natural gas, but with lower net carbon emissions. Electricity generation from biomass has the advantage of being storable, which enables electricity production to be fired up and down and can help offset some of the intermittency of wind and solar generation in an integrated electricity system.

Solar Energy as a Renewable Source

The sources of possible electricity from renewable energy category, vastly outnumbers that of the conventional oil based source category. Arif, Aslam, and Hussein (2017), stated that the renewable energy resource with the highest potential is solar energy, considering only the surface land above the sea level. This is to say, if countries utilize solar photovoltaic farms over sea areas, this may increase the surface area which they use to capture the sun to generate electricity.

Domestic solar resources are particularly strong: average global horizontal irradiance (GHI), the measure used to determine potential for solar photovoltaic (PV) development, ranges from 5 to 7 kilowatt-hours per square meter per day (kWh/m2/day) throughout most of the country, with some areas nearing 8 kWh/m2/day (C-SERMS, 2015). For perspective, Germany, which has nearly half of the world's installed solar PV capacity, has an average GHI of just 2.9 kWh/m2/day and very few locations above 3.5 kWh/m2/day. Distributed solar

PV generation at the household and commercial levels can play an especially important role in Jamaica's energy mix (Ahmed et al, 2013).

Energy Storage Technology in Future Power Systems

According to IRENA (2017), future energy systems will rely on a large array of services based on effective, economical electricity storage. This overabundance of service needs, with varying performance requirements, suggests an important role for many different storage technologies. The following are the current list of energy storage technologies in no particular order.

Flywheel Energy Storage

According to Yasmeen (2009), the operating principle of a flywheel energy storage system (FESS) (Figure 2.2) is that electrical energy is converted to kinetic energy and stored in the flywheel, and the kinetic energy can be converted back to electrical energy when required later.

Pumped Hydro Energy Storage

IRENA (2017) states that pumped hydro (PHS) (Figure 2.3), stores energy in the form of gravitational potential energy by pumping water between two reservoirs located at different heights. When electricity demand is low, water is pumped through the penstock from the lower end towards the upper water reservoir, using external power.

Compressed Air Energy Storage

Yasmeen (2009) highlighted that compressed air energy storage systems (CAES) (Figure 2.4), involve the use off-peak power to pressurize air into an underground reservoir (salt cavern, abandoned hard rock mine or aquifer) which is then released during peak daytime hours to power a turbine/generator for power production.

Thermal Energy Storage

Thermal energy storage (TES) (Figure 2.5) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power generation. TES systems are used particularly in buildings and in industrial processes (Sarbu and Sebarchievici, 2018).

Battery Energy Storage

There are many battery technologies available, such as lithium-ion, lead-acid, NiCd, Vanadium Redox-Flow, sodium-sulphur, among others currently being researched (Yasmeen, 2009). Figure 2.6 shows a large Lithium NMC battery bank while Figure 2.7 illustrates some characteristics of Lithium-ion variations.

Battery energy storage systems are typically configured in one of two ways: a power configuration or an energy configuration, depending on their intended application (GE Renewable Energy, n.d.). In a power configuration, the batteries are used to inject a large amount of power into the grid in a relatively short period of time, which requires a high inverter-to-battery ratio. A typical application would be to simulate a turbine ramp up for frequency regulation, spinning reserve, or black start capacity. In an energy configuration, the batteries are used to inject a steady amount of power into the grid for an extended amount of time (IRENA, 2018; GE Renewable Energy, n.d.).

Renewable Energy Source Safety Considerations

All energy sources have some impact on our environment. Fossil fuels such as coal, oil, and natural gas do substantially more harm than renewable energy sources by most measures, including; air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. However, this gives a promising opportunity for a reduction in energy use; the aim must be to exclude standby usage, not only to decrease energy use, but also for health and safety reasons (Mohamed, 2016).

The exact type and intensity of environmental impacts of RE, varies depending on the specific technology used, the geographic location, and a number of other factors. By understanding the current and potential environmental issues associated with each renewable energy source, we can take steps to effectively avoid or minimize these impacts as they become a larger portion of our electric supply.

Summary of Literature Review

This chapter demonstrates the relevant literature to provide a synopsis of the available renewable energy technologies to Jamaica; along with given a better understanding on the emerging trend of microgrids systems. It covered the following four sub-topics; The first sub-topic was achieving electricity through the method of decentralized power generation, using microgrid systems. The second sub-topic was the discussion of the available sources of renewable energy that Jamaica can add or increase in its energy portfolio mix. Thirdly, the sub-topic and importance of energy storage technology in future power generation systems. This sub-topic went on to list several energy storage technologies and gave concise information on its operation and application.

The fourth and final sub-topic discussed the safety concerns using renewable energy sources. As with every technology, disadvantages are present in various aspects such as: cost, the time spent in set-up of system, scalability and consistency of sources based on location and market. However, the international performance of renewable energy is continuously positive and it is growing rapidly in installed capacity in many countries, some countries have 100 percent portfolio mix of renewable energy technologies installed.

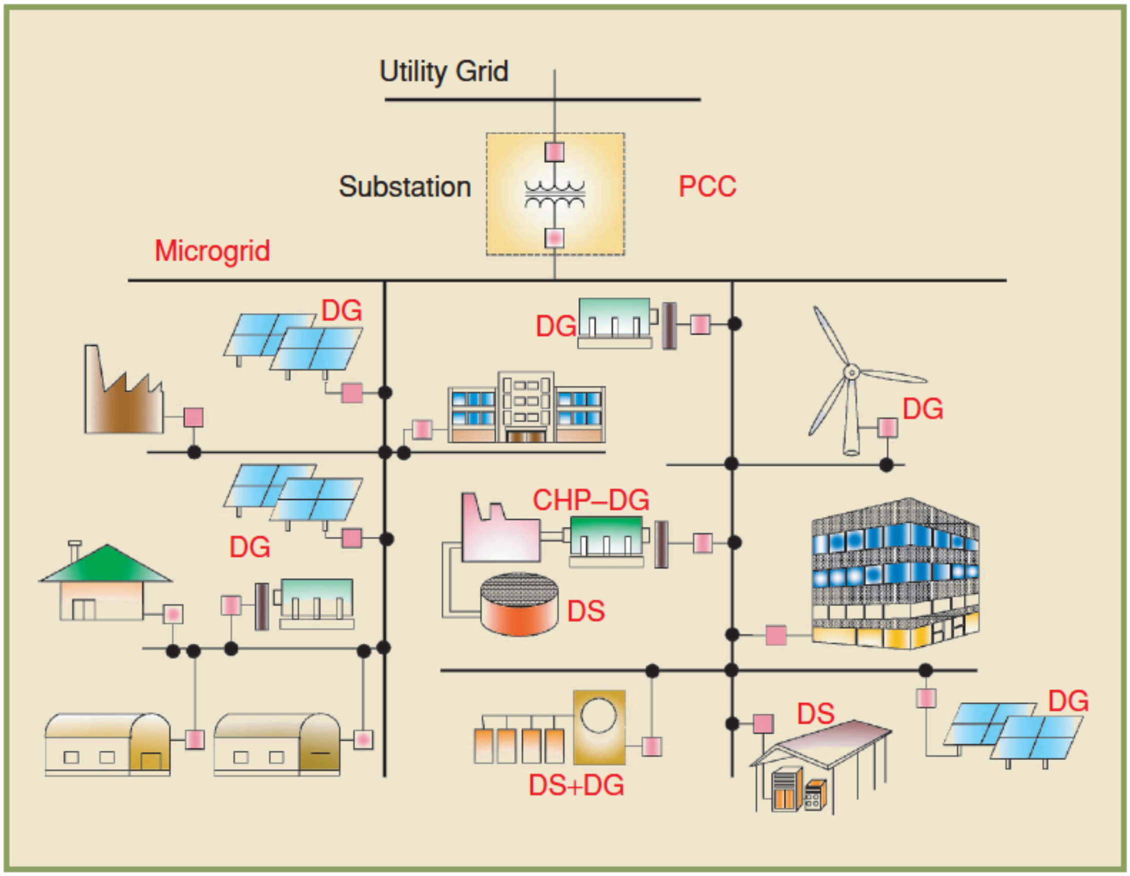

Figure 2. 1 A Typical Microgrid Structure Including Loads and DER Units Serviced by a Distribution System. Reprinted from (Dimeas, et al., 2008).

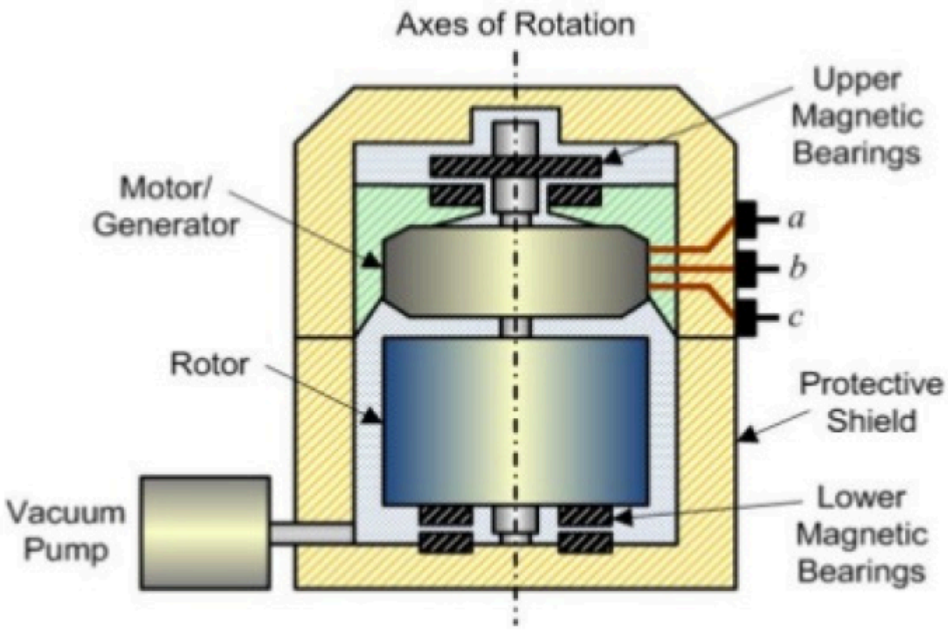

Figure 2.2 Displays the operating principle of a flywheel energy storage system (FESS). Reprinted from (Yasmeen, 2008).

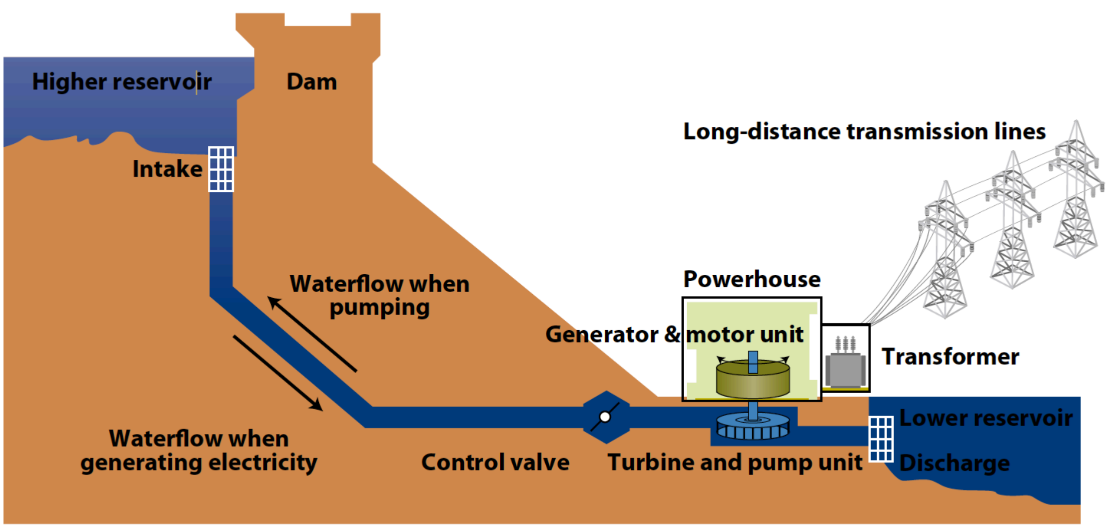

Figure 2.3 Schematic of a typical conventional pumped hydro storage system. Reprinted from (IRENA, 2017).

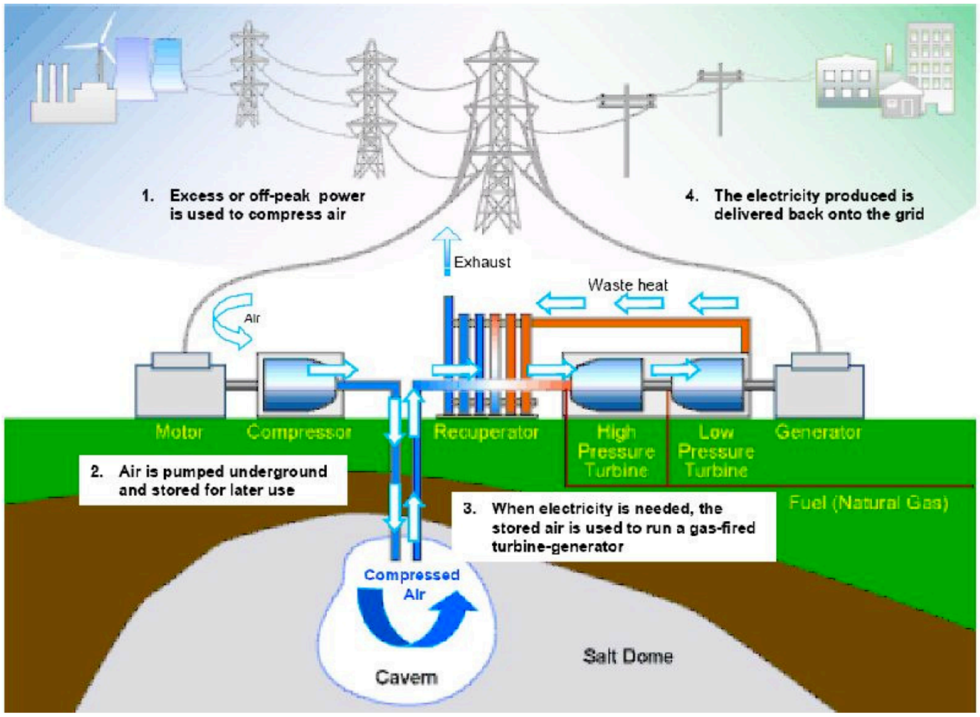

Figure 2.4 Displays the principle operation of a “Compressed Air Energy Storage” (CAES). Reprinted from (Yasmeen, 2008)

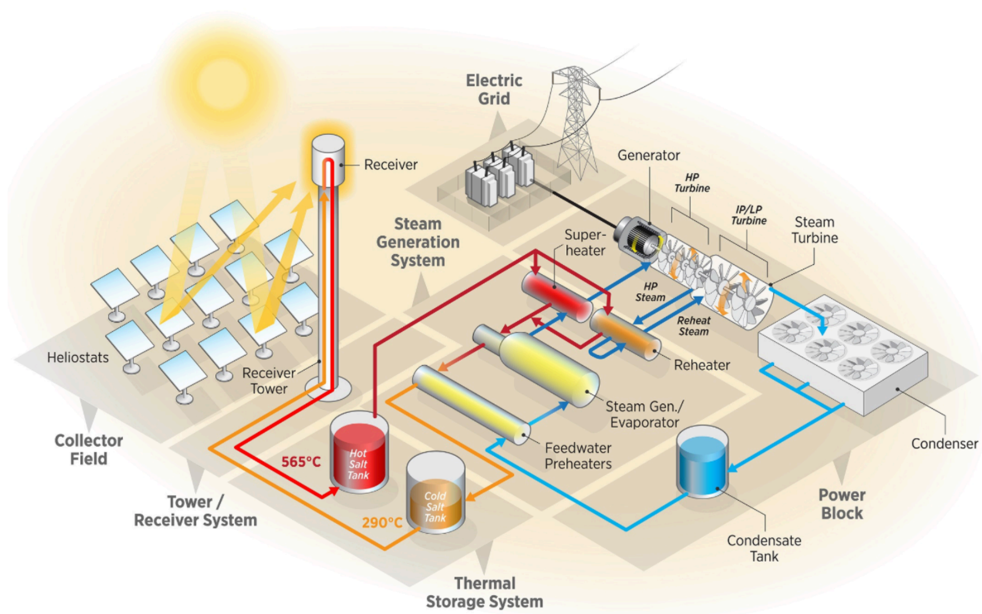

Figure 2.5 Displays a “Thermal Energy System” (TES) used for energy storage. Reprinted from (Rajput, 2017)

Figure 2.6 A 56 MW Lithium Nickel Manganese Cobalt Energy Storage System. Reprinted from Energy Insider.

Key active material	lithium nickel manganese cobalt oxide	lithium manganese oxide	lithium nickel cobalt aluminium	lithium iron phosphate	lithium titanate
Technology short name	NMC	LMO	NCA	LFP	LTO
Cathode	$LiNi_xMn_yCo_{1-x-y}O_2$	$LiMn_2O_4$ (spinel)	$LiNiCoAlO_2$	$LiFePO_4$	variable
Anode	C (graphite)	C (graphite)	C (graphite)	C (graphite)	$Li_4Ti_5O_{12}$
Safety					
Power density					
Energy denisty					
Cell costs advantage					
Lifetime					
BES system performance					
Advantages	-good properties combination -can be tailored for high power or high energy -stable thermal profile -can operate at high voltages	-low cost due to manganese abundance -very good thermal stability -very good power capability	-very good energy and good power capability -good cycle life in newer systems -long storage calendar life	-very good thermal stability -very good cycle life -very good power capability -low costs	-very good thermal stability -long cycle lifetime -high rate discharge capability -no solid electrolyte interphase issues
Disadvantages	-patent issues in some countries	-moderate cycle life insufficient for some applications -low energy performance	-moderate charged state thermal stability which can reduce safety -capacity can fade at temperature 40-70°C	-lower energy density due to lower cell voltage	-high cost of titanium -reduced cell voltage -low energy density

Figure 2.7 Illustration of Lithium chemical properties along with their advantages and disadvantages. Reprinted from (IRENA 2017).

CHAPTER III
METHODOLOGY

This chapter details the research methods that were used in the study, as they influence the validity and reliability of the findings. It is vital that the research methods utilized be in line with the nature of the research problem. This chapter covers the research design, target population, data collection procedures, and data analysis.

The researcher's objectives throughout this study are to:

1. Identify if a microgrid based network of power transmission would have a more efficient power output versus the current traditional transmission system;
2. Determine the socio-economic considerations for Jamaica to encounter if and when these ventures are undertaken and;
3. Analyze the cost benefits of the implementation of a higher mix of renewable portfolio, in comparison to Jamaica's natural gas and petroleum based fuel mix.

Research Design

The research methodology for this thesis paper is a descriptive quantitative approach. Identifying the current available renewable energy technologies along with its developments, required discussions through interviews with SMEs on current systems in addition to literature review.

Secondary sources such as international and local government reports and researches found in scholarly databases, came to be the most valuable component to this thesis paper, as there were numerous constraints during the study. The literature search focused primarily on electrification technologies, microgrid systems, and renewable energy literature published in the field from 1999 – 2018. Extensive analysis of "Jamaica's National Energy Policy: 2009-2030" and the Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS), both were national and internationally government funded studies conducted over several years before being published respectively.

Notwithstanding such use of the qualitative method, quantitative approaches were introduced later on in the study. After interviewing SMEs and from findings of the literature review on cost benefit analysis, evaluation, and effectiveness, industry standards and software were used to quantify the actual economic feasibility of introducing RE as a larger energy portfolio mix for electrification.

Population

The thesis study was focused on the island state of Jamaica with a population sample of the municipal city of Portmore. Portmore is located in the parish of St. Catherine south of the island and approximately 5 miles from the country's capital city, Kingston. It is the fastest growing municipal in the Caribbean. Figure 3.1 shows the approximated location of the population area of study.

Data Collection

The researcher obtained data used in the study from interviews with SMEs and interpretation of relevant secondary sources. Notwithstanding that each project is unique and the fact that there are limited centralized information on the various costs for the commissioning of a new power plant in the island state of Jamaica; the researcher utilized the most current and relevant source at the time of this study. Table 3.1 is a summarized table of information for capital cost estimates for utility scale electricity generating plants; and it takes into consideration capital investment cost which includes factors such as planning, development, testing, etc. In addition, Table 3.2 which focused on energy storage technologies was used to support further analyses in Chapter 4.

As mentioned above, the costs used to determine the capital investment, operational and maintenance costs in the study, assumes that it is the same cost that the island state of Jamaica will employ. The researcher focused on the utility size cost for RE technology in order to associate like for like cost when comparing the alternative fossil fuel technology.

Equally important were the assumptions made for the power and transmission efficiency of the chosen power systems. Fossil fuel power system are not one hundred percent (100%) efficient and the ANGCC system studied is determined to be thirty-five percent (35%) efficient see chapter 4 paragraph 4 for calculation. In addition to the power factor, Jamaica's transmission system typically experiences a twenty percent (23%) power loss after being transmitted to the point of consumption. Notwithstanding these points, fossil fuel plants typically have a longer useful life range and the selected technology presented a forty (40) to fifty (50) years useful life.

The selected Solar PV Tracking technology had comparatively different power generation and energy transmission efficiencies to ANGCC system mentioned previously. When effectively installed and assuming decentralized placements of electricity generation, the Solar PV tracking system can present a power efficiency rate ranging from 85 – 95% (Penn State, n.d.).

Ultimately, assumptions were made on the data and values used in this benefit cost analysis; from overnight cost of constructing the plants, to the needed power capacity, to the mean useful life of the respective system and to the emissions costs factor, all of which are conservative.

Data Analysis

Anjorin (2014), states that, a dollar's worth today is more than a dollar's worth in the future, theoretically. The Microsoft Excel software was used extensively to manipulate numerical values and to perform numerical computation. A visual presentation of information was generated to show some numerical relationship between several variables or quantities under certain defined conditions. Data was carefully selected and organized into summary tables and graphs that show the most relevant information. These types of data analysis and management will show exactly how the findings relate to the objective.

According to BusinessDictionary.com, economic feasibility is the analysis of a project's costs and revenues in an effort to determine whether or not it is logical and possible to complete. Benefit-Cost Analysis (BCA) estimates and sums up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile; and therefore will be used in the study to determine feasibility of the alternative power plant options.

BCA is commonly used to evaluate public projects. Benefits of a nonmonetary nature need to be quantified in dollar terms as much as possible and factored into the analysis. The following are the steps in the BCA process; 1) Identify all users' benefits expected to arise from the project, 2) quantify these benefits in dollar terms as much as possible, so that different benefits may be compared against one another and against the costs of attaining them, 3) identify sponsor's or capital costs, 4) quantify these costs in dollar terms as much as possible, to allow comparisons, 5) determine the equivalent benefits and costs during the base period; use an interest rate appropriate for the project and 6) accept the project if the equivalent users' benefits exceed the equivalent capital costs. These values contained in the Benefit-Cost Ratio can be expressed as

$$\mathrm{BC(i)} = \frac{B}{C} = \frac{B}{I+C}, \ \mathrm{I + C' > 0}$$

where if the ratio is greater than 1, then the project is feasible.

In conducting the analysis, the assumed efficiency ratings were used to determine the nominal power capacity of the individual power system. Just under twenty-five megawatts (25MW) of power capacity is needed to supply the municipal city of Portmore (K. Green, personal communication, June 7, 2018). In the base case, a discount rate of 7% is selected for the analysis. This is due to the recommendation of U.S. Energy Department (2018) when conducting pubic investments and regulatory analyses.

Table 3.1 Estimates of Power Plants Capital and Operating Cost. Reprinted from (EIA, 2016).

	Plant Characteristics		Plant Costs (2016$)			
Technology	Nominal Capacity (MW)	Heat Rate (Btu/kWh)	Overnight Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	NEMS Input
Coal						
Ultra Supercritical Coal (USC)[10]	650	8,800	3,636	42.1	4.6	N
Ultra Supercritical Coal with CCS (USC/CCS)[11]	650	9,750	5,084	70	7.1	Y
Pulverized Coal Conversion to Natural Gas (CTNG)	300	10,300	226	22	1.3	N
Pulverized Coal Greenfield with 10-15 percent	300	8,960	4,620	50.9	5	N
Pulverized Coal Conversion to 10 percent biomass –	300	10,360	537	50.9	5	Y
Natural Gas						
Natural Gas Combined Cycle (NGCC)	702	6,600	978	11	3.5	Y
Advanced Natural Gas Combined Cycle (ANGCC)[13]	429	6,300	1,104	10	2	Y
Combustion Turbine (CT)	100	10,000	1,101	17.5	3.5	Y
Advanced Combustion Turbine (ACT)	237	9,800	678	6.8	10.7	Y
Reciprocating Internal Combustion Engine (RICE)	85	8,500	1,342	6.9	5.85	N
Uranium						
Advanced Nuclear (AN)	2,234	N/A	5,945	100.28	2.3	Y
Biomass						
Biomass (BBFB)	50	13,500	4,985	110	4.2	N
Wind						
Onshore Wind (WN)	100	N/A	1,877	39.7	0	Y
Solar						
Photovoltaic – Fixed	20	N/A	2,671	23.4	0	N
Photovoltaic – Tracking	20		2,644	23.9	0	N
Photovoltaic – Tracking	150	N/A	2,534	21.8	0	Y
Storage						
Battery Storage (BES)	4	N/A	2,813	40	8	N

Table 3.2 Energy Storage Technology Options. Reprinted from (Ahmed et al., 2013).

Option	Description	Current Status of Technology	Scale of Technology	Cost per Discharge Power	Levelized Cost of Storage	Annual Operating Costs	Suitability for Jamaica
Lead-acid batteries	Used widely with off-grid technologies. Most commonly used to store electrical energy from PV systems, including at the household level.	Mature technology	10 MW or less	USD 300–800 per kW	USD 0.25–0.35 per kWh_{life}	USD 30 per kW per year	Suitable for off-grid applications. Environmental and health concerns arise from lack of maintenance and disposal of old batteries.
Nickel-cadmium (NiCd) batteries	Have higher energy density and cycle life than lead-acid batteries, but are more expensive.	Mature technology. As with lead-acid, used for standalone power systems but not considered suitable for bulk storage due to cost.	A few kW to tens of MW	USD 3,000–6,000 per kW (in bulk storage)	Data not available	Data not available	Same as above.
Lithium ion batteries	Rechargeable batteries used widely in mobile applications due to high energy density. Various types exist and offer different pros and cons.	Emerging technology. Need further development for power generation energy storage, but offer promise.	10 MW or less	USD 400–1,000 per kW	USD 0.30–0.45 per kWh_{life}	USD 25 per kW per year	Needs more R&D.
Liquid-metal (NaS) batteries	Other types of batteries are being developed for utility-scale storage applications. NaS batteries utilize the sodium-sulfur reaction and require high operating temperatures.	Emerging, pre-commercial technology	100 MW or greater	USD 1,000–2,000 per kW	USD 0.05–0.15 per kWh_{life}	USD 15 per kW per year	Expensive and not yet developed enough to be worthwhile. Potential to pair either with wind power could be useful in the future, once the technology is more developed.
Vanadium redox and zinc-bromine flow batteries (VRB and ZBB)	Flow batteries utilize electrochemical energy storage, just like lead-acid batteries, but require little maintenance. Large capacity potentials make VRBs suitable for wind energy storage, while ZBBs are more appropriate for smaller-scale systems.	Emerging, pre-commercial technology	25 kW–10 MW	USD 1,200–2,000 per kW	USD 0.15–0.25 per kWh_{life}	USD 30 per kW per year	Expensive and not yet developed enough to be worthwhile. Potential to pair either option with wind power could be useful in the future, once the technology is more developed.
Pumped-storage hydro	Most commonly used for large-scale energy storage, and to complement solar and wind. At times of low power demand, excess electricity is used to pump water uphill into a sealed-off reservoir. During periods of peak demand (or low energy production), the stored water is released through a hydropower plant, pushing a turbine that rotates a generator to produce electricity. Requires hydro resources and mountainous landscapes.	Mature technology	Typically 200 MW or greater	USD 1,000–4,000 per kW	USD 0.05–0.15 per kWh_{life}	USD 5 per kW per year	Very suitable. Assessments needed to identify viable sites.

Figure 3. 1 Showing the various cities in the Caribbean state island of Jamaica. Reprinted from CIA World Factbook: Jamaica (2015).

CHAPTER IV
RESULTS AND ANALYSES OF DATA

The primary objective of this study, recorded in Chapter Three (3), is to investigate whether it will be economically feasible for Jamaica, increasing its renewable energy portfolio mix, upon a microgrid system in order to achieve power efficiency.

This chapter presents the results of the research detailed in the previous sections, the projected cost for capital investment and operating and maintenance cost for the selected power plants systems. In addition to the previously mentioned costs, emissions costs, efficiency and other assumed values are summarized in this chapter. This chapter is essential in ensuring that the research questions were adequately addressed and ultimately helps in determining the degree of success of the study.

Table 4.1 Summary of Data Collected

The values for Fixed O&M cost, Variable O&M cost, Overnight cost, and Battery Energy Storage cost were taken directly from Table 3.1 which was reprinted from EIA, (2016). The selected power plants are Advanced Natural Gas Combined Cycle and Solar Photovoltaic Tracking. In Chapter 3, paragraph 12 of this document, it was mentioned that currently in the city of Portmore, approximately twenty-five megawatts (25MW) is being used according to K. Green (personal communication, June 7, 2018), a member of Jamaica's public power company.

When sizing a power system, it is often recommended to have power capacity slightly above the expected usage in order to accommodate demand surges and factors which may change due to conditions. The power capacity that will be utilized in the analysis will be 30MW for both the Natural Gas and Solar PV power plants. There is however a fuel cost associated with natural gas plants and will be determined subsequently in the calculations to follow.

In the selected natural gas power plant, it assumes a power efficiency of 54% based on its heat rate of 6300 Btu which according to EIA (May, 2018) will divide into the equivalent Btu content of a kWh of electricity (3412 Btu) to obtain the generator's efficiency. The Solar PV plant power efficiency in the same time was determined differently. Assuming that each panel will generate its rated output, the average conversion loss was used to determine the system's efficiency. Converting from DC to AC, Solar PV systems experiences an average 90% power efficiency. These calculations are shown below:

LNG plant efficiency = $\frac{Equivalent\ Btu\ Content}{Heat\ Rate} = \frac{3412}{6300}$ = 0.542 = $\underline{\underline{54\%}}$

Solar PV plant efficiency = $\frac{85+95}{2}$ = 0.90 = $\underline{\underline{90\%}}$

The transmission and distribution efficiency of the PV power system is assumed to be negligible due to decentralization of power generation which results in power being used in a localized section, eliminating need for long distance transmission and distribution. In contrast, from Chapter 1 paragraph 3 and Figure 1.5, it can be determined that Jamaica currently experiences a loss of approximately 23.5% and can be calculated as follows:

Avg. Power Loss = $\frac{Power\ Losses}{2} = \frac{22.3+24.7}{2}$ = $\underline{\underline{23.5\%}}$

Transmission efficiency rate = 100% - 23.5% = $\underline{\underline{76.5\%}}$

Chapter 3 discussed the useful life span of the two selected plants. These ranges were averaged; an assumption of forty-five (45) useful life years was determined for LNG power plant, in contrast the Solar power plant averaged a useful life of thirty-five (33) years. These calculations are shown below:

Average Useful Life of LNG Plant = $\frac{40 + 50}{2}$ = 45

Average Useful Life of Solar Plant = $\frac{25 + 40}{2}$ = 32.5 = 33

Another factor that was taken into consideration was the social impact cost of carbon dioxide emissions. According to Rechenberger (n.d.), natural gas plants produces approximately 0.572 kg of carbon dioxide (CO2) per kWh of electricity generated. In addition, it has been estimated that it cost two-hundred and twenty dollars per ton ($220/ton) of carbon dioxide emitted on social impact (Diaz and Moore, as sited in Than, 2015). This emission cost is calculated as follows:

Electricity generated from plant = 30MW

Converting MW to kW = 30 x 1000 = 30,000kW

Accounting for daily runs and converting to kW to kWh

30,000kW x 16hrs (peak usage per day) x 365 days = 175,200,000 kWh

Converting carbon produced per kWh = 0.572 x 175,200,000

= 100,214,400 kg

Converting kg to ton = 100,214,400 x 0.001

= 100,214.4 ton/yr

Table 4.2 Calculation of Summed Costs

The values within Table 4.2 were calculated assuming an estimated average peak of 16 hours per day for the year, the population consuming 25MW will use 146,000 MW per year. The following items were calculated as follows:

<u>LNG Plant Calculations</u>

Capital Investment = Capacity in kW x Overnight Cost

= (30 MW x 1000) x $1,104

= <u>$33,120,000.00</u>

Fixed O & M Cost = kW x FOM Rate

= 30,000 kW x $10

= <u>$300,000.00</u>

Variable O & M Cost = MWh x VOM Rate

= 146,000 MWh x $2

= <u>$292,000.00</u>

Emission Cost = $220 x 100,214.4 ton

= <u>$22,047,168.00</u>

EIA (April 6, 2018), published that, fuel cost can be determined by dividing the heat rate of the plant's generator with the heat content of the fuel (LNG). The lowest and highest heat rate that was circulated in the year 2017 were 990 and 1081 Btu respectively, the average of which is 1036 Btu. The current published cost for LNG is $5.03/1000 cubic feet. Therefore, to supply 146,000 MWh for the year running the 30MW capacity plant, 175,200,000 KWh will be created.

Amount of fuel per kWh = $^{Heat\ Rate}/_{Heat\ Content}$ = 6300/1036

= 6.1 ft^3/kWh

Fuel Used per year = Fuel used per kWh x Generated Power

= 6.1 x 175,200,000 = 1.06872 Billion Units

Fuel Cost per year = 1,068,720 x $5.03

= $5,375,662

According to The Gleaner, (June 2017), it was published that power outages cost the Jamaican economy approximately JMD $340 million. Converting for $US equivalent:

Blackout Cost = $340 million / 130 (exchange rate in 2017)

= $2,615,384.62

At a rate of $US 0.40/kWh, the estimated revenue is $58,400,000.00

Revenue = kWh usage per year x $0.40

= 146,000,000 kWh x $0.40

= $58,400,000

N.B. that the cost for fuel is not accounted for in either the fixed or variable operating and maintenance costs. Moreover, the power company passes on the costs of fuel to their registered customers. This cancels out additional expenses and a portion of the revenue received by the state's power company.

Solar Plant Calculations

Capital Investment = Capacity x Overnight Cost

= (30 MW x 1000) x $2,534

= $76,020,000

Fixed O & M Cost = 30,000 kW x $21.8

= $654,000.00

Variable O & M Cost = 146,000 MWh x $0

= $0

Emission Cost is assumed to be negligible.

For the purpose of comparison, the rate of $US 0.40/kWh, will be assumed for estimating the revenue for both ANGCC and Solar PV power plants. This amount is $58,400,000.00

Energy Storage Cost

Lead-acid Batteries

Initial Cost = 146,000,000 kWh x ($^{\$0.25 + \$0.35)}/_{2}$) = \$43.8 Million

Annual Cost = 30,000 kW x \$30 = \$900,000

Lithium ion Batteries

Initial Cost = 146,000,000 kWh x ($^{\$0.30 + \$0.45)}/_{2}$) = \$54.75 Million

Annual Cost = 30,000 kWh x \$25 = \$750,000

Pumped Hydro Storage

Initial Cost = 146,000,000 kWh x ($^{\$0.05 + \$0.15)}/_{2}$) = \$14.6 Million

Annual Cost = 30,000 kW x \$5 = \$150,000

Compressed Air Storage

Initial Cost = 146,000,000 kWh x ($^{\$0.10 + \$0.20)}/_{2}$) = \$21.9 Million

Annual Cost = 30,000 kW x \$5 = \$150,000

Table 4.3 Cost Benefit Calculations

ANGCC Power Plant

Benefit (B) = Revenue – (O & M Expenses + Disbenefits)

= \$58,400,000.00 – (\$300,000.00 + \$292,000.00 + \$22,047,168.00.00

+ \$2,615,384.62 + \$5,375,662.00)

= \$27,769,785.38

Net Present Value was determined by using the Excel software which is equal to

\$353,105,060.31

Benefit-Cost Ratio = $B/_C$ = $\$353{,}105{,}060.31/_{\$33{,}120{,}000.00}$

= 10.66

Solar Power Plant

To ensure reliability of the power system, energy storage systems are needed.

Benefit (B) = Revenue – (O & M Expenses + Disbenefits)

= \$58,400,000.00 – (\$654,000.00 + \$900,000.00)

= \$56,846,000.00

The Excel software was utilized again to determine NPV which is equal to

\$677,571,913.36

Benefit-Cost Ratio = $B/_C$ = $\$677{,}571{,}913.36/_{\$76{,}020{,}000.00 + \$4{,}380{,}000.00}$

= 8.43

Further Analysis with Varying Scenarios

Hybrid Scenario

This setup involves the use of the Solar PV system in conjunction with the ANGCC plant and no energy storage system integrated. Assuming 50% usage for both systems each associated recurring expenses will be at halved.

Benefit (B) = Revenue – (O & M Expenses + Disbenefits)

= $58,400,000.00 – [(ANGCC Expenses and Disbenefits at 50%

+ (PV System Expenses at 50%)]

= $58,400,000.00 – ($15,315,107.31 + $327,000.00)

= $42,757,892.69

The Excel software was utilized to determine NPV which is equal to **$509,649,705**

Benefit-Cost Ratio = B/C = $\$509{,}649{,}705 / \$76{,}020{,}000.00 + \ \$33{,}120{,}000.00$

= 4.67

Scenario PV + PHS

This setup involves the use of the Solar PV system for power generation in integrated with Pumped Hydro Storage as the energy storage system.

Benefit (B) = Revenue – (O & M Expenses + Disbenefits)

= $58,400,000.00 – ($654,000 + $150,000)

= $57,596,000

The Excel software was utilized to determine NPV which is equal to **$601,287,561**

Benefit-Cost Ratio = B/C = $\$601{,}287{,}561 / \$76{,}020{,}000.00 + \ \$14{,}600{,}000.00$

= 6.64

Results Obtained

Table 4.1 Showing the Collected Data for each of the Selected Alternative Power System.

Description	LNG Power Plant	PV Power Plant
Power Capacity (MW)	30	30
Overnight Cost per kW($/kW)	1104	2534
O & M Fixed Cost ($US/kW-yr)	10	21.8
O & M Variable Cost ($US/MWh)	2	0
Power Efficiency (%)	54	90
Useful Life	45	33
Transmission & Distribution Efficiency (%)	76.5	-
Emission Cost $220/ton (tone)	117,250	-

Table 4.2 Showing the Summed Amount for Each Cost for the Different Alternatives.

Description	ANGCC Plant	Solar PV System
Capital Investment	$33,120,000.00	$76,020,000.00
Fixed O & M Costs	$300,000.00	$654,000.00
Variable O & M Costs	$292,000.00	$0
Average Useful Life	45 Years	33 Years
Fuel Cost	$5,375,662.00	$0
Emission Costs	$47,768,864.00	$0
Blackout Costs	$2,615,384.00	$0
Revenues	$58,400,000.00	$58,400,000.00
Discount Rate	0.07	0.07

Table 4.3 Cost Benefit Analysis of Each Individual Alternative Power System and Scenarios.

Description	**ANGCC Plant**	**PV Power System with BESS**	**Hybrid Scenario**	**Scenario PV+PHS**
Capital Investment (C)	$33,120,000	$80,400,000	$147,780,000	$90,620,000
Net Annual Profit (B)i	$353,105,060	$677,571,913	$331,791,432	$601,287,561
B/C Ratio	10.66	8.43	4.67	6.64

CHAPTER V
FINDINGS, CONCLUSION AND RECOMMENDATIONS

Discussion

Jamaica had outlined an energy source portfolio mix which anticipated over 12% renewable source by 2018. Jamaica exhibits significant and largely unexploited potential for developing renewable energy resources. If fully developed, these resources could transform the country into a net energy exporter. Hydropower comprises the majority of renewable power generation in Jamaica and worldwide. Regionally, the resource is ideal for states with hilly topography and high rainfall rates. In member states with substantial agricultural activity, biomass and municipal solid waste provide a flexible and easily accessible entry point to renewable energy generation. (C-SERMS, 2015).

IRENA (20217) also went on to state the following, "Electricity storage technologies are emerging as a critical part of the solution to increase access to electricity, as well as providing stability services to mini-grids, improving the power quality and increasing the potential share of variable renewables in such remote grids" (p.12). However, after conducting the study and even with economics of scale, where the larger the units the lower the cost, we can see that energy storage, mainly BES and PHES, is quite expensive as a means of supplying constant energy or finding suitable locations respectively. Nonetheless if used in a power configuration, BES can aid in the power stability of a power generation system and Pumped Hydro would be the economically ideal technology for energy storage if suitable location exists.

Conclusion

Returning to the aim of the study, the researcher had set out to find the following; 1) If a microgrid-based network of power transmission would cause better power output versus the current traditional transmission system, 2) determine the socio-economic considerations for Jamaica to encounter if and when these ventures are undertaken and 3) if the economic feasibility of Jamaica increasing its renewable sources in the energy portfolio mix.

According to the findings of the study, we see that a good portion of energy is generally lost during transmission and distribution inefficiencies. Decentralizing the transmission and distribution of power by using microgrids would reduce losses and with localized monitoring of the grids, utility plants can examine and control power loss.

As with all power system, there are safety considerations that must always be taken into account; and RE technology is no different. However, if Jamaica seeks to venture into RE sources on a larger scale, there are massive benefits in carbon dioxide (CO2) reductions that would occur.

Finally, the analysis of multiple scenarios shows that, at this point in time Jamaica can implement Solar PV systems to offset the massive dependence on fossil fuel and still be profitable. This would utilize the abundant source of solar energy that exists in the country during peak production. Another scenario shows where Solar PV can be supplemented by ANGCC systems where gaps occur and still be economically feasible for Jamaica.

Limitation

One of the major limitations faced throughout the study was the lack of data specific to the population. Furthermore, due to the researcher's inability to travel to the population of study, there was limited opportunity to obtain additional information to make a more absolute conclusion. There were other factors that could have be taken into consideration: socio-economic benefit cost such as employment, quality of life, etc. and disbenefits such as the effects of noise population due to decentralization of power generation.

Recommendations

In the year 2009, the government of Jamaica aimed to, by publishing "Jamaica's National Energy Policy 2009-2030, which envisioned a modern, efficient, diversified and environmentally sustainable energy sector providing affordable and accessible energy supplies with long-term energy security. It is recommended that the following actions be done in order to support or improve its goal:

1. Conduct studies to identify a detail list of the different socioeconomic factors that would enhance the population, and the disbenefits for continuing with fossil base power generation.
2. Develop a public-private-partnership plan to make it desirable for home owners and company owners to invest in renewable energy. This is order to reduce the direct capital cost on the government of Jamaica needing to add to its budget.
3. Research and design unique hybrid system that are economically feasible and can be constructed in a short period.

4. This would be supplemented with a project management plan that would enable the country to shift its power transmission into a multi-microgrid system and thus laying the structure for renewable energy technologies implementation, at which point should have more economical capital costs.

REFERENCE

Anjorin, A. (2014). Feasibility of Making Solar Energy Available in The Northern Region of Nigeria. Dissertation (PhD). Colorado Technical University

Arif, S., Aslam, M, and Hussain, A. (2017). Emerging Renewable and Sustainable Energy Technologies: State of The Art

Ahmed, A., Konold, M., Lucky, M., Makhijani, S., Ochs, A., and Weber, M. (2013) Jamaica Sustainable Energy Roadmap: Pathways to an Affordable, Reliable, Low-Emission Electricity System. Washington, DC: Worldwatch Institute.

Auth, K., Killeen, P., Konold, M., Musolino, E., and Ochs, A. (2015) Caribbean Sustainable Energy Roadmap and Strategy (C-SERMS): Baseline Report and Assessment. Washington, DC: Worldwatch Institute.

Bahramirad, S., Kavousi-Farda, A., and Khodaei, A. (2016). Improved Efficiency, Enhanced Reliability and Reduced Cost: The Transition from Static Microgrids to Reconfigurable Microgrids. The Electricity Journal.

Broese van Groenoub, A., McCabea, A., and Pojania, D. (2018). Energy Policy. The Application of Renewable Energy to Social Housing: A Systematic Review. 114. Retrieved from https://doi.org/10.1016/j.enpol.2017.12.031

Dimeas, A., Katiraei, F., Hatziargyriou, N., and Iravani, R. (2008). Microgrid Management: Controls and Operations Aspects of Microgrids. IEEE Power and Energy Magazin

Fallahzadeh-Abarghouei, H., Hasanvand, S., Nayeripour, M., and Waffenschmidt, E. (2017). A New Approach to Transform an Existing Distribution Network into A Set of Micro-Grids for Enhancing Reliability and Sustainability.

Future Power System. (2016, March 4). Retrieved from https://www.carbonbrief.org/uk-needs-a-smart-power-revolution-says-infrastructure-commission/www-gifcreator-me_r3xltb-1

GE Renewable Energy: Battery Energy Storage Solutions (Bess). Retrieved from https://www.ge.com/renewableenergy/hybrid/battery-storage

Hatziargyriou, N., Ise, T., Kroposki, B., Lasseter, R., Morozumi, S., and Papatlianassiou, S. (2008). A Look at Microgrid Technologies and Testing Projects from Around the World. IEEE Power and Energy Magazine

IRENA (2017), Electricity Storage and Renewables: Costs and Markets to 2030, International Renewable Energy Agency, Abu Dhabi

Jamaica. (2015). Retrieved from https://www.cia.gov/library/publications/resources/the-world-factbook/geos/jm.html

Jamaica Public Service Company (JPSCo). How We Deliver Power to You. Retrieved from https://www.jpsco.com/about-jps/how-we-serve-you/how-we-deliver-power-to-you/

Lund, H. (2007). Renewable Energy Strategies for Sustainable Development

Mason, M. (2009). A Perspective on Partnership for Overcoming the Barriers to the Implementation of Renewable Electricity Production. Thesis (MSc). Lund University

Mohamed, A. (2016). Investigation into the Feasibility of the Utilisation of Renewable Energy Resources in Libya. (PhD). Nottingham Trent University

National Renewable Energy Laboratory (NREL). (n.d.). Energy Analysis: Useful Life. Retrieved from https://www.nrel.gov/analysis/tech-footprint.html

Penn State, (n.d.). Utility Solar Power and Concentration (EM812): Efficiency of Inverters. Retrieved from https://www.e-education.psu.edu/eme812/node/738

Rajput, G. (2017). Molten Salt Thermal Energy Storage Market Size to Witness Significant Growth 2015 – 2023. CMFE News. Retrieved from https://cmfenews.com/molten-salt-thermal-energy-storage-market-size-to-witness-significant-growth-2015-2023/

Rechenberger, D. (n.d.). Wingas. Retrieved from https://www.wingas.com/fileadmin/Wingas/WINGAS-Studien/Energieversorgung_und_Energiewende_en.pdf

Sarbu, I., and Sebarchievici, C. (2018). Sustainability Review: A Comprehensive Review of Thermal Energy Storage. Retrieved from https://www.mdpi.com/2071-1050/10/1/191/pdf

The Gleaner, (2017, June 9). JPS Blackout Costs Country $340 Million. Retrieved from http://jamaica-gleaner.com/article/lead-stories/20170609/jps-blackout-costs-country-340-million

Than, K., (2015, January 12). Estimated Social Cost of Climate Change Not Accurate. Stanford Times. Retrieved from https://news.stanford.edu/2015/01/12/emissions-social-costs-011215/

U.S. Energy Information Administration (EIA). May 2018. What is the efficiency of different types of power plants? Retrieved from https://www.eia.gov/tools/faqs/faq.php?id=107&t=3

U.S. Energy Information Administration (EIA). November 2016. Capital Cost Estimates for Utility Scale Electricity Generating Plants. Retrieved from https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost_assumption.pdf

U.S. Department of Energy, (2018, March). 2018 Discount Rates. Retrieved from https://www.energy.gov/sites/prod/files/2018/04/f50/2018discountrates.pdf

Yasmeen, F. (2009). Techno Economical Analysis of Solid Oxide Iron–Air Redox Battery for Power Generation and Energy Storage. (MSc). University of South Carolina

Zaremba, H. (2017). The Caribbean Is Poised to Become the Next Major Oil Region. Retrieved from https://oilprice.com/Energy/Crude-Oil/The-Caribbean-Is-Poised-To-Become-The-Next-Major-Oil-Region.html

https://www.eia.gov/KIDS/energy.cfm?page=biomass_home-basics

http://www.businessdictionary.com/definition/economic-feasibility.html